Foliar pests and pathogens of *Eucalyptus dunnii* plantations in southern Queensland

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Summary

Eucalyptus dunnii is grown in plantations in subtropical Queensland, beyond its endemic distribution of northern NSW. As the plantation industry has expanded into subtropical Australia there has been an increase in the incidence of defoliating insects and foliar pathogens. This study measured the incidence and severity of damage (abiotic damage, fungal damage, insect defoliation, insect-induced necrosis and or other insect damage), four times over one year, in eight plantations aged 1, 2, 3 and 4 y where *E. dunnii* was the dominant species: four near Brisbane and four near Bundaberg. Multidimensional scaling (MDS) analysis showed little separation between the two regions so all data for the study were combined. During the study period, the monthly rainfall was substantially lower than over the previous 30 y, particularly in all months except September to January where higher-than-average rainfall occurred in both regions. This resulted in a strong seasonal effect. The greatest damage was caused by defoliating insects (39.6% of total damage) most notably chrysomelids, followed by insect necrosis (19.2%). The pests and diseases causing most damage (e.g. chrysomelids) were present most of the year and are known to be multivoltine in subtropical regions of Australia. Only chrysomelid damage increased over the survey period, while fungal damage decreased slightly in the same period. Insect necrosis was present all year round, with most damage occurring in winter and least damage in summer. Other insect damage was highest in 1.75–3-y-old trees, peaking in winter at 9.1% in the 1.75-y-old trees. This study has provided some interesting insights into the incidence and severity of abiotic stress, pests and pathogens over four seasons. These findings may influence future plantation management of pests and diseases in establishing plantations.

Keywords: plantations; pest; pathogens; diseases; defoliation; *Eucalyptus dunnii*

Introduction

With the recent expansion of the plantation industry in Australia there has been an increase in the incidence of defoliating insects and foliar pathogens (Burgess and Wingfield 2002; National Forest Inventory 2003; Stone *et al.* 2003; Smith *et al.* 2005; Carnegie 2007a,b). Most pests and pathogens of Australian eucalypt plantations are native and originate in surrounding native forest (de Little 1989). Defoliation by pathogens and pests, depending upon intensity, may adversely affect growth and development of plantations, often resulting in economic loss (Stone *et al.* 1998; Collett and Newmann 2002; Jordan *et al.* 2002; Carnegie and Ades 2003; Pinkard *et al.* 2006a,b). In plantations, severe defoliation is usually restricted to younger trees prior to canopy closure (Carnegie *et al.* 2005).

Eucalyptus dunnii has only recently been grown as a plantation species in southern Queensland (Lee *et al.* 2000); its natural distribution is in small pockets in northern New South Wales (NSW) (Benson and Hagar 1993). The natural populations are estimated to occupy less than 80 000 ha and *E. dunnii* is therefore listed as an endangered species (Briggs and Leigh 1988). Almost 39 000 ha of *E. dunnii* plantations have been established in both NSW and Queensland (Smith and Henson 2007), with 25–40% of plantations in coastal north-eastern NSW and south-eastern Queensland using this species (Parsons *et al.* 2006).

Eucalyptus dunnii is susceptible to a wide range of defoliating insects across a range of site types, but its rapid growth allows it to compensate for losses from most insects (Lee *et al.* 2006). Research conducted under the Hardwoods Queensland Pests and Diseases Challenge in early 2000 identified the defoliating pests and diseases of *E. dunnii* as leaf beetles (*Paropsisterna cloelia*, *Paropsis atomaria*), swarming scarabs (*Automolus*, *Liparetrus* spp.), Christmas beetles (*Anoplognathus* spp.), bubble-gall wasp, lerps (*Creiis* spp. only in northern NSW at this time) and tip bugs (*Amorbus* spp.). Bubble gall wasps and flea beetles (*Chaetocnema* spp.) were considered to be emerging and potentially highly damaging defoliators of *E. dunnii* (Lee *et al.* 2003; 2006). Chrysomelid leaf beetles are the most common eucalypt foliar insect pests (Carnegie *et al.* 2005; Nahrung 2006). *Paropsisterna cloelia* is commonly found on *E. dunnii* and *E. grandis* in subtropical Australia and is the most damaging species on *E. dunnii* in north-eastern NSW (Lee *et al.* 2003; Carnegie *et al.* 2005). Christmas beetles are also common and damaging on several hosts in south-eastern Queensland (Lee *et al.* 2003; Carnegie *et al.* 2005). Swarming scarabs (*Automolus* spp.) have caused significant defoliation on several occasions in south-eastern Queensland (Lee *et al.* 2003; Carnegie *et al.* 2005; Lee *et al.* 2006). Occasionally larvae of eucalypt sawflies (*Pergagrapta* spp. and *Perga* spp.) and leaf-blister sawflies (*Phylacteophaga* spp.) have caused severe defoliation (Carnegie *et al.* 2005). The only key pathogen listed for *E. dunnii* was *Mycosphaerella* (Lee *et al.* 2003).

In the present study, leaf defoliation, damage, necrosis or discolouration caused by abiotic means, insect pests or fungal pathogens in 1–4-y-old *E. dunnii* plantations in south-eastern Queensland were examined over four seasons.

Methods

Site selection

Eight plantations aged 1, 2, 3 and 4 y were selected in which *E. dunnii* was the dominant species; four near Brisbane and four near Bundaberg 360 km north of Brisbane. Each estate occurred in an area of 10 km² consisting of agricultural grazing land and small remnants of native forest. All plantations were 40–60 ha in size on mainly yellow podzolic soils, with similar topography and surroundings (i.e. proximity to native forest, pasture and roads). Compartments including other species were not selected for study.

Plot establishment

Plots were established in plantations using the Crown Damage Index (CDI) sampling procedure (Stone *et al.* 2003), with 80 trees per plantation. Each plantation was divided into eight compartments of equal size, and a random point in each compartment was selected to establish a plot of a diagonal row of 10 trees. In the field, each of the plots was located and marked using a GPS (Magellan GPS Blazer12) and the same trees were assessed during each visit.

Identifying target pests and diseases to categorise damage

A preliminary survey of all plantations was undertaken to identify target pests and diseases and to develop damage categories. Each plantation was sampled for 10 h for diseased foliage and insect pests. Insects were collected by hand opportunistically and stored in 70% ethanol. Diseased foliage was collected in paper bags. Specimens were examined at high magnification using an Olympus stereo microscope. Taxonomic journal articles, texts and internet sources were consulted (e.g. CSIRO Division of Entomology 1970; Sutton 1980; Hamlin 1990; Crous 1998; www.csiro.au/org/entomology), and Simon Lawson of the Queensland Forestry Research Institute assisted by confirming many of the insect identifications. Fifteen types of damage were grouped into seven categories: abiotic damage (three groups—yellowing, reddening and necrosis), fungal damage, insect defoliation, insect necrosis and other insect damage (Fig. 1 and Table 1). The relative abundance (low, moderate or high) of each form of damage was subjectively estimated at the time of collection.

Incidence and severity of damage

Foliar damage was assessed using a modified version of the CDI system for damage assessment of eucalypt crowns (Stone *et al.* 2003), which rated the incidence and severity of each damage category separately. The incidence of damage is the percentage of affected leaves on a single tree, while the severity is the percentage of leaf area affected on these affected leaves. The following increments were used for both incidence and severity: 5, 25, 50, 75 and 100%. The incidence multiplied by the severity divided by 100 provided a percentage of total damage to the crown. Each tree was assessed for each damage category. Each plantation was rated for the impact of pests and diseases at four sampling times: end of winter (August 2004), spring (November 2004), summer (February 2005) and autumn (May 2005). Consequently, data for each plantation cover a 12-month period.

Climate data

Rainfall and air temperature data (data drill) were obtained from the Bureau of Meteorology SILO services (http://www.longpaddock.qld.gov) for the Rosevale plantation (27.1495°S, 145.90396°E) 35 km south-east of Brisbane, and the Rosedale (23.17175°S, 146.06046°E) 25 km north-west of Bundaberg (Fig. 2).

Statistics and multivariate analyses

Multivariate analyses were carried out using a Primer 5 statistical package (Clarke and Gorley 2001). The Bray–Curtis similarity coefficient was employed to construct a similarity matrix from the log $(n+1)$ transformed values of each of the damage categories. This matrix was then subjected to non-metric multidimensional scaling (MDS) ordination. One-way crossed analysis of similarities (ANOSIM; Clark 1993) was carried out to ascertain whether the compositions of damage categories differed significantly between regions, plantations and seasons. The factors employed in each of the tests are specified in the results. In each test, the null hypothesis that there were no significant differences among damage categories was rejected if the significance level (P) was $<5\%$. $R > 0.1$ were considered significant, and similarity percentages (SIMPER; Clark 1993) were used to identify which damage categories made the greatest contribution to those differences.

Results

During the study period, the monthly rainfall was substantially different from that of the previous 30 y, with many months having no rainfall (Fig. 2). The Brisbane estate received only half (199 mm) of the average rainfall (383 mm), most notably with less than 8 mm occurring in the normally wet months of January–April (Fig. 2a). Annual rainfall recorded at the Bundaberg estate was also lower than average (326 mm compared to an average of 505 mm), with 92% of rainfall occurring between November and February. An extreme rainfall event occurred in January 2005, when an extra 32.5 mm of rain above the monthly average of 86.3 mm fell over a few days (Fig. 2b). At each estate, the average minimum temperatures of the study period did not differ significantly from those of the previous 30 y (1970–2000), while there was a slight increase in maximum temperatures.

MDS analysis showed little separation between the two regions when combining all damage categories, so data for the two regions were combined (Fig. 3a). MDS analysis showed a strong seasonal effect when all damage categories were combined (Fig. 3b). The autumn and winter surveys, which followed periods of low rainfall, were distinctly separated from the spring and summer surveys. A one-way ANOSIM test of all damage categories in the four seasons of sampling showed significant ($R = 0.69$) differences. MDS analysis revealed a distinct separation of 1-y-old plantations from other age classes when comparing categories of

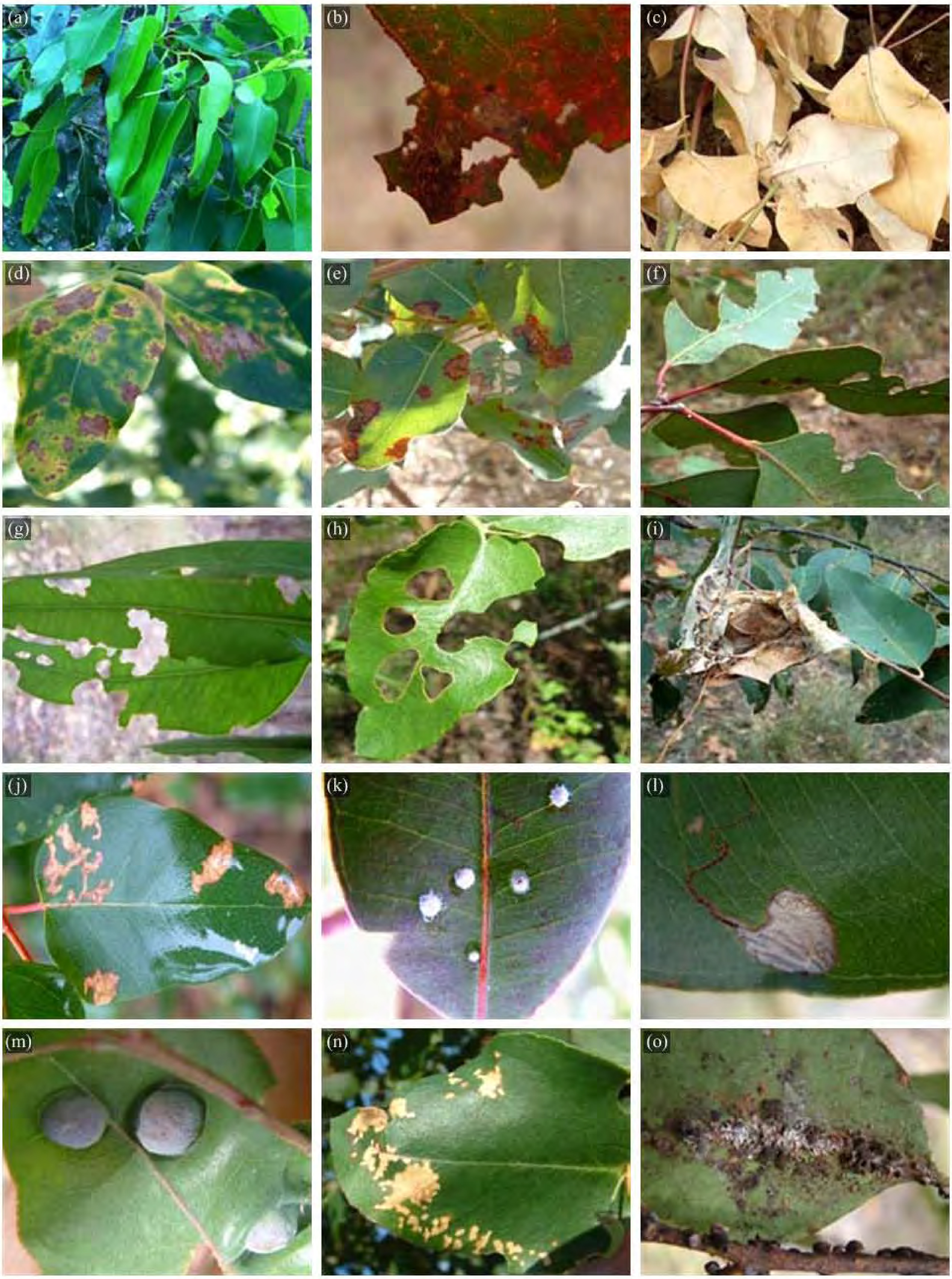

Figure 1. Damage categories: (a)–(c) = abiotic damage, (d)–(e) = fungal damage, (f)–(i) = insect defoliation, (j)–(k) = insect necrosis, and (m)–(o) = other insect damage. (a) = foliar yellowing, (b) = foliar reddening, (c) = abiotic necrosis, (d) = general fungal damage, (e) = *Mycosphaerella* leaf blight, (f) = general insect defoliation, (g) = *Chrysomelid* defoliation, (h) = *Gonipterus* defoliation, (i) = leaf tier caterpillar, (j) = *Chaetocnema* necrosis, (k) = pysllid necrosis, (l) = *Phylacteophaga* blisters, (m) = bubble gall wasps, (n) = mirid (*Rayiera* sp.) damage, and (o) = *Eriococcus coriaceus* (scale) damage with sooty mould

Table 1. Abiotic, fungal and insect foliar damage recorded in 1- to 4-y-old plantations of *Eucalyptus dunnii* in Brisbane and Bundaberg (August 2004 – May 2005). Incidence = proportion of affected leaves on a single tree; severity = proportion of the area of a leaf affected. Leaf age preference (where known) in superscript—J = juvenile, M = mature, YM = young mature, A = all ages. References in parentheses.

Damage category	Likely causal agent(s)	Description of foliar damage
Abiotic—foliar yellowing	Nutrient or water deficiency, pest- or disease-induced stress	Incidence may range from a single leaf to the whole tree being affected by foliar yellowing. Severity may range from minor yellowing such as slight interveinal chlorosis to major yellowing of the entire leaf on both sides.
Abiotic—foliar reddening	Nutritional stress or insect damage	Incidence may range from a single leaf to the whole tree being affected by foliar reddening. Severity may range from minor yellowing such as slight interveinal reddening to major reddening of the entire leaf on both sides.
Abiotic—necrosis	Generally water deficiency, also high temperatures and frost	Incidence may range from a single leaf to the whole tree being affected by physiological necrosis. Severity may range from minor necrosis such as small patches to entire necrosis of the leaf on both sides.
Fungal damage	Coelomycete^{J}: *Teratosphaeria* anamorphs *T. cryptic, T. nubilosa, Dissoconium dekkeri* Hyphomycete: *Cercospora* spp. Ascomycete^{J}: *Mycosphaerella heimii, M. marksii* (Abbott *et al.* 1993; Carnegie *et al.* 1994; Andjic *et al.* 2007)	Incidence may range from a single leaf to the whole tree being affected by fungal damage. Severity may range from minor necrosis such as small necrotic patches to entire necrosis of the leaf on both sides. Note: Different fungal species have different symptoms such as different size and shape and colour of the lesions and different fruiting bodies. All fungal pathogens were included in this damage category.
Insect defoliation	Chrysomelidae^{A}: *Paropsis atomaria, P. obsolete, P. variolosa* *Chaetocnema* spp. *Paropsisterna cloelia, Paropsisterna* spp. *Cryptocephalus* spp. (de Little and Madden 1975; Tanton and Khan 1978; Lawrence *et al.* 2003) Curculionidae^{YM}: *Gonipterus* sp. and *Oxyops* spp. (Took 1955; Elliot and de Little 1984) *Lepidoptera* spp.	Incidence may range from a single leaf to the whole tree being affected by defoliation. Severity may range from minor damage such a small area of leaf being removed by chewing to the entire leaf being removed.
Insect necrosis	Tortricid$^{J, YM}$: *Strepsicrates* spp. *Chaetocnema* spp.^{M} (flea beetles) Hemiptera^{A}: (sap-sucking bugs) Psyllidae (lerps): *Cardiaspina*^{M}, *Creiis*^{YM} and *Glycaspsis*^{YM} (Brennan *et al.* 2001; Bell Miner Associated Dieback Working Group 2007; DPI NSW 2007) *Phylacteophaga* spp^{YM} (leafblister sawfly) (NZ Farm Forestry Association 2009)	The larvae of this moth causes malformation of foliage and defoliation Incidence may range from a single leaf to the whole tree being affected by total insect necrosis. Severity may range from minor necrosis such as small necrotic patches to entire necrosis of the leaf on both sides. Note: The main criterion in distinguishing insect necrosis from physiological necrosis or fungal necrosis is that insect necrosis is usually associated with chewing of the leaf lamina by the mouthparts of the feeding insect. Note: All forms of necrosis caused by insect species were included in this category of damage.
Other insect damage	Miridae: *Rayieria* sp.^{YM} (Carnegie *et al.* 2008) Chalcidoidea: Several species of foliar gall wasps including *Ophelimus* spp.^{V} (personal observations) *Eriococcus coriaceus*^{A}	From necrotic leaf speckling to complete foliar necrosis Minor damage (a few galls per leaf) to extreme damage where large clusters distort the lamina. In severe cases branches may snap from the weight of clusters of galls. Scale colonise the stem and secretions often become covered with a black sooty mould.

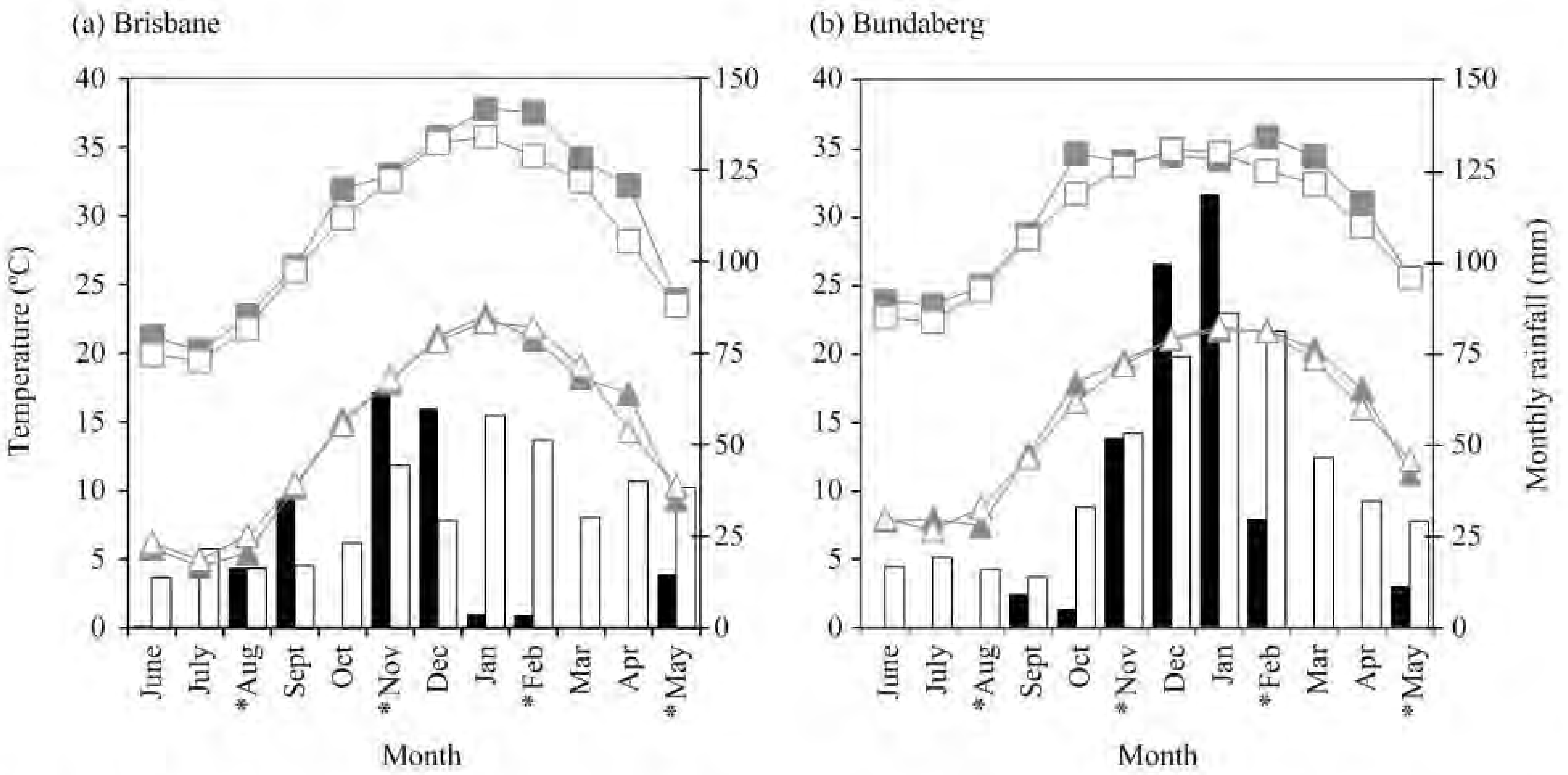

Figure 2. Monthly average minimum (triangles) and maximum (squares) temperature, and total monthly rainfall (bars) were obtained from the Bureau of Meteorology SILO services (http://www.longpaddock.qld.gov) for (a) the Rosevale plantation 35 km south-east of Brisbane, and (b) the Rosedale plantation 25 km north-west of Bundaberg. Solid colours represent data from the period of study (June 2004 – May 2005); white from previous 30 y (1970–2000). * indicates survey time.

damage as assemblages (Fig. 3c). The 1-y-old plantations have a greater proportion of juvenile foliage, even in their second year.

Almost 40% of all damage was caused by defoliating insects (and 36% of this was chrysomelid damage), followed by insect necrosis (19.2%), while abiotic causes were responsible for 28.4% of damage (Fig. 4). Less insect defoliation ($P < 0.05$) was observed in the 1-y-old plantations compared with those 2–4 y old, with most damage recorded in February and May 2005 surveys (Fig. 5). Only chrysomelid damage increased over the survey period, being greatest in 2.5- and 2.75-y-old trees (43.4 and 40.7%, respectively) and in 4.5- and 4.75-y-old trees (38.9 and 35.4%, respectively). Fungal damage decreased slightly over the survey, with the biggest outbreak occurring in winter (average 11.9%) causing most damage on the 2-y-old trees (29.9%). Insect necrosis was present all year round and damage ranged from 2.5 to 19.4%, most occurring in winter and least in summer. Other insect damage was greatest in 1.75–3-y-old trees, peaking in winter at 9.1% in the 1.75-y-old trees. Abiotic effects peaked in winter (32.5%) and then remained below 25% for the rest of the survey, with least damage in summer.

Discussion

More than a decade of surveys have identified the main pests and diseases in the plantations of southern Queensland. Surveys since 2000 have mainly concentrated on a subset of plantations 1–2 y of age with a previous history of insect or fungal problems (Lawson *et al.* 2008), and generally occur during the wet season between October and April. The current study, however, is the first to survey damage over the four seasons in one year. In the *E. dunnii* plantations several trends were detected: there was overlap between the two regions; chrysomelids and other insect defoliators caused the most damage, followed by insect necrosis and abiotic necrosis; there was some separation between sampling times (season), and there was less damage in 1-y-old plantations compared with older plantations.

In the current study, rapid leaf turnover was observed; dry conditions caused leaf loss, followed by a flush of juvenile foliage after rain. *Eucalyptus dunnii* may revert partially, or entirely, to juvenile foliage following the loss of the adult leaves (Steinbauer 2002). Juvenile leaves have quite a different composition of plant compounds compared with adult foliage (Steinbauer 2002) and some pests and diseases occur more readily on this nitrogen-rich foliage than on the mature foliage (Steinbauer *et al.* 1998; Brennan *et al.* 2001; Lawrence *et al.* 2003). However, while juvenile foliage is known to be preferred by many pests and pathogens, the rapid leaf turnover and seasonally dry weather observed in the current study appeared to prevent population build-up, and thus less damage overall was observed on juvenile leaves.

Chrysomelid insect defoliators caused the most damage at all sampling times, but more so in summer and autumn. Chrysomelids are multivoltine and active for up to 10 months of the year in subtropical areas (Carnegie *et al.* 2005). For example, in *E. cloeziana* plantations in south-eastern Queensland, *Paropsis atomaria* produced 2–4 generations in 7 months (September–April) (Duffy 2006; Nahrung *et al.* 2008) and showed positive flexibility in relation to availability of flush foliage (Carnegie *et al.* 2005). These pests are recognised as a significant threat to eucalypt productivity in Queensland (Lawson and King 2002; Nahrung 2006) and affect the growth rate, height, volume and possibly pulpwood quality of trees (Candy *et al.* 1992). Nahrung's (2006) survey (September 2004 to April 2005) found the most common pest species present in 3-y-old *E. dunnii* plantations in south-eastern Queensland were *Paropsisterna cloelia* (two generations) and *P. atomaria*. Following the current and Nahrung's survey,

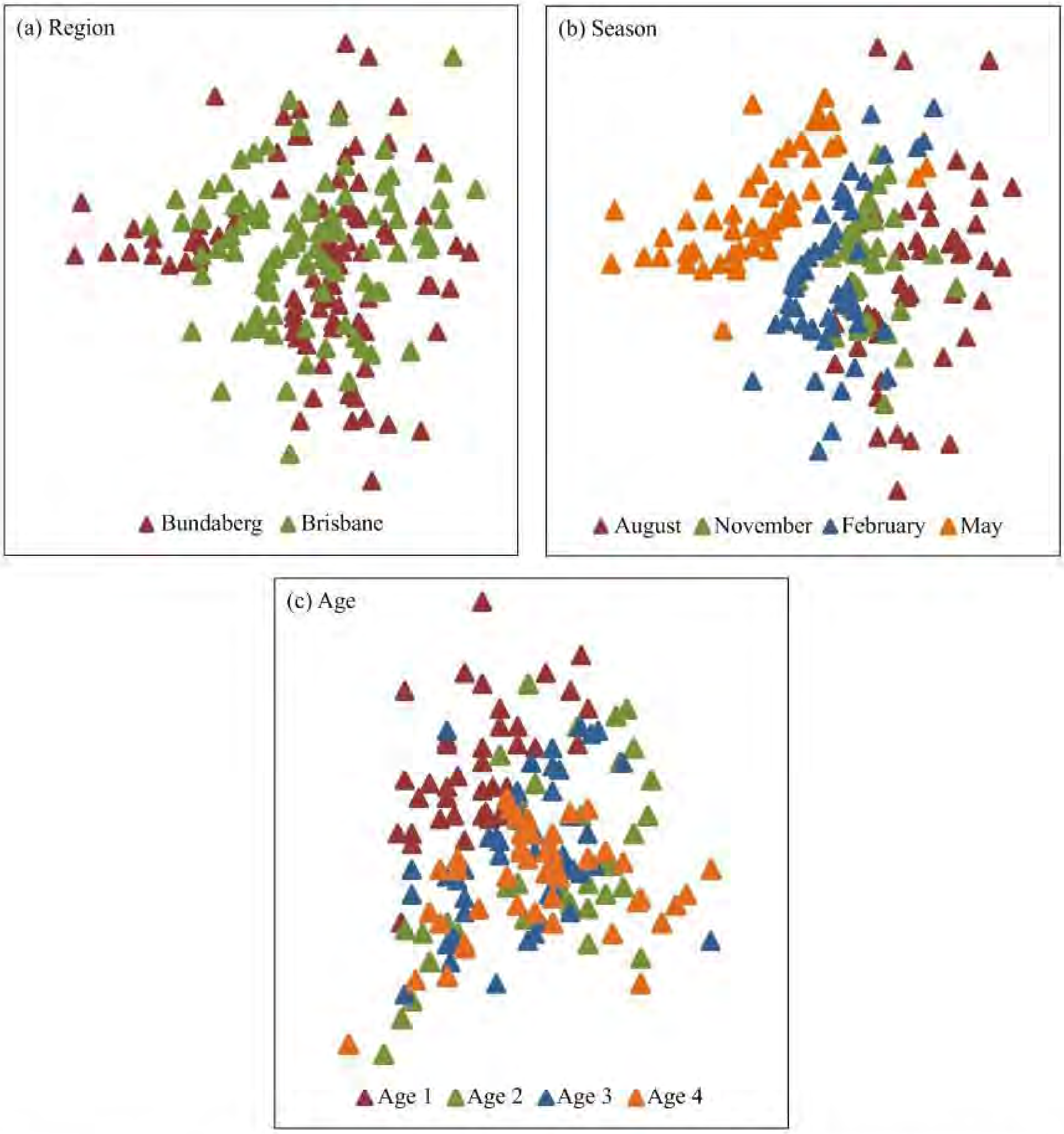

Figure 3. Two-dimensional MDS ordination of the second-stage similarity matrix containing the correlations between similarity matrices constructed from the measure of all damage categories in all samples. (a) = region; (b) = season (containing four distinct groups, with the November 2004 and February 2005 surveys extensively overlapping); (c) = age (showing a distinct separation of 1-y-old plantations from other age classes)

Lee *et al*. (2006) also identified the most important defoliators of *E. dunnii* in Queensland and NSW in mid- and late summer (January–February) as *Paropsisterna* and *Paropsis*.

Another significant defoliator pest of young *E. dunnii* plantations in subtropical Australia, the pysllid *Creiis lituratus,* has three or more generations per year (Carnegie *et al*. 2005) and caused severe damage in 1–5-y-old plantations (Angel *et al*. 2003; Carnegie and Angel 2005), particularly in trees that were already under some abiotic stress (Angel *et al*. 2003). Severe damage from *C. lituratus* can kill *E. dunnii* trees (Carnegie and Angel 2005), and repeated cycles of defoliation and re-foliation can result in tree death (Angel *et al*. 2008). Pysllids are often prolific and can build up numbers very quickly during the wettest part of the year (Dent 1991), hence in the present study most damage occurred immediately after the wet season (May). Overall, pysllid damage in the current study was much lower than observed in northern NSW. Several factors may contribute to this. Firstly, rapid leaf turnover, as occurred in the current study, is known to interfere with the pest's life cycle (Angel *et al*. 2003). Secondly, temperature plays an important role in the life cycle of the *Creiis*, and as temperature increases, adult longevity decreases (Angel *et al*. 2008). The summer temperatures in south-eastern Queensland may lessen damage from pysllids.

Almost 13% of all damage was inflicted by insects causing foliage necrosis. Taxa responsible include Chaetocnemae (flea beetles), Hemiptera (sap-sucking bugs), Psyllidae (*Cardiaspina*, *Creiis* and *Glycaspsis*) and *Phylacteophaga* spp. (leafblister sawfly). The flea beetle caused most damage in spring and autumn in Brisbane, and in autumn in Bundaberg. Lee *et al*. (2006) found most foliage damage caused by flea beetle in *E. dunnii* occurred in late winter–early spring (August–September). Sapsuckers caused significantly more damage in the 1-y-old Bundaberg plantations during the unseasonably dry months leading to the autumn survey, and in all Brisbane plantations. The Brisbane spring survey

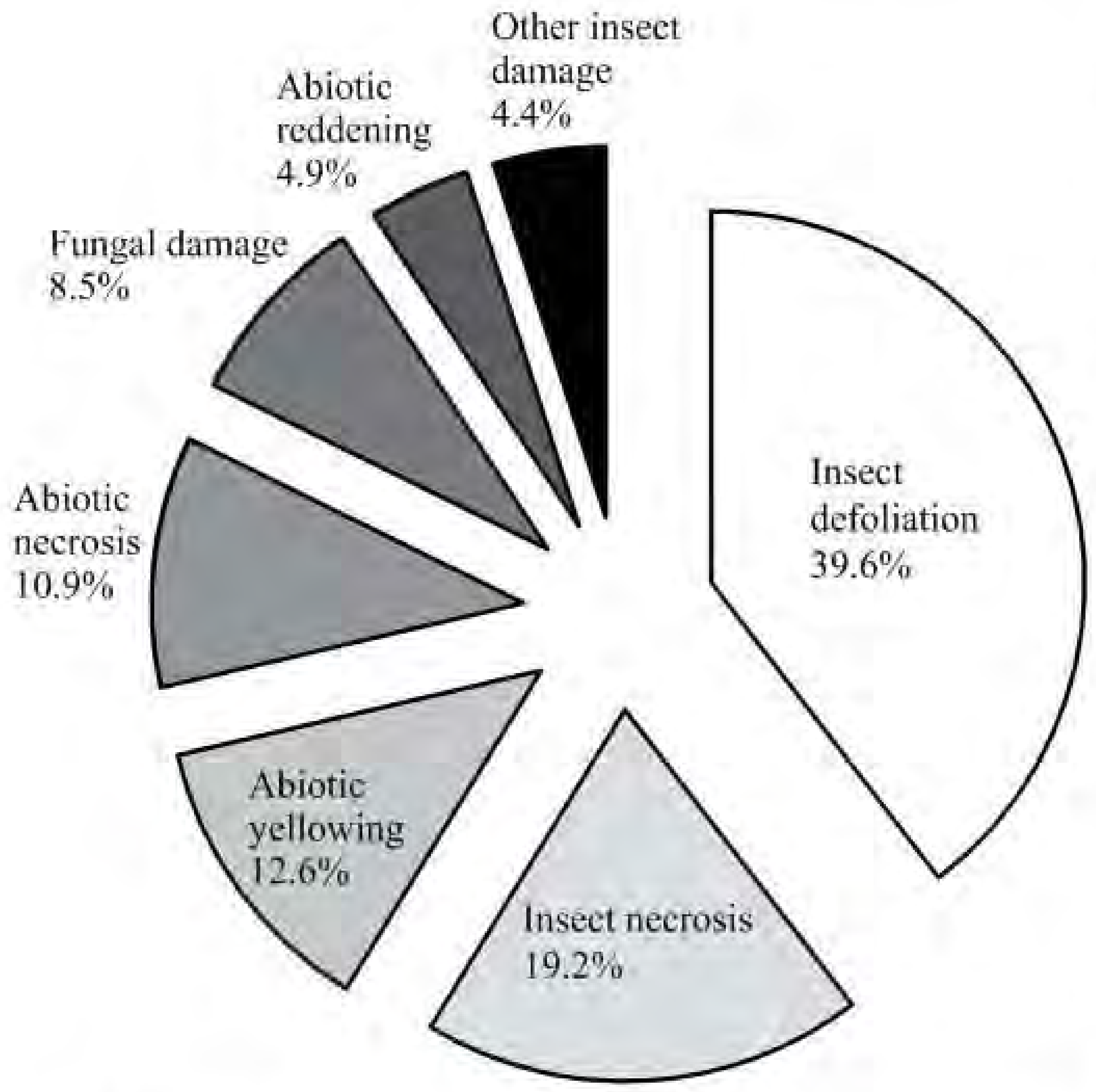

Figure 4. Extent of foliar damage by insect, fungal and abiotic means in 1–4-y-old *Eucalyptus dunnii* plantations near Brisbane and Bundaberg from August 2004 to May 2005.

revealed elevated insect necrosis following higher-than-average rainfall in all plantations.

Lee *et al.* (2006) listed other important defoliators that were not observed in the current study; the swarming scarabs (*Automolus*, *Liparetrus* and *Sericesthis* spp.) which damage growing tips and new flush foliage in spring and early summer (October–December), and the Christmas beetles (*Anoplognathus* spp.) in the upper crown in early summer (Lee *et al.* 2006). *Eucalyptus dunnii* are also often defoliated by Christmas beetles (Smith and Henson 2007). *Automolus* sp. is considered to be a common and damaging pest species of *E. dunnii* in subtropical regions (Carnegie *et al.* 2005). While the Christmas beetles and swarming scarabs can cause severe episodic damage, this occurs in a short window early in the growing season, and consequently these insects may not have been visible during surveys associated with the current study. Additionally, little damage was caused by several other insects including *P. froggatti* (leaf blister sawfly), *Rayiera* sp. (mirids), foliar gall wasps, scale and leaf tier caterpillar. Damage caused by these insects can also be episodic. Trees can generally recover from this episodic damage, in contrast to the constant moderate damage caused by chrysomelids.

All plantations produced juvenile foliage in response to rainfall following water stress, resulting in a greater proportion of juvenile to adult foliage. They also lost this foliage rapidly due to water stress. Abiotic symptoms due to stress accounted for 20% of the damage in this survey and had the potential to predispose the trees to further damage as observed in water-stressed *E. dunnii* plantations in northern NSW (Stone 2001). The growth rate of eucalypts, including *E. dunnii*, may be reduced if the canopy damage exceeds 38% (Angel *et al.* 2003; Pinkard *et al.* 2006a,b). Damage above this level proportionally reduced the growth increment over the following 6 months (Carnegie and Angel 2005). In the current study, insect defoliation was 32 and 29.7% in summer and autumn, respectively. Heavily defoliated trees often respond by producing larger quantities of flush growth in the next season; this response can make them more susceptible to defoliators, thus initiating a feedback loop of increasing susceptibility to defoliation (Landsberg 1990). Based on field observations it was likely that the younger plantations had greater rates of defoliation by chrysomelids, although the older plantations had a greater tendency to retain damaged foliage. Thus when

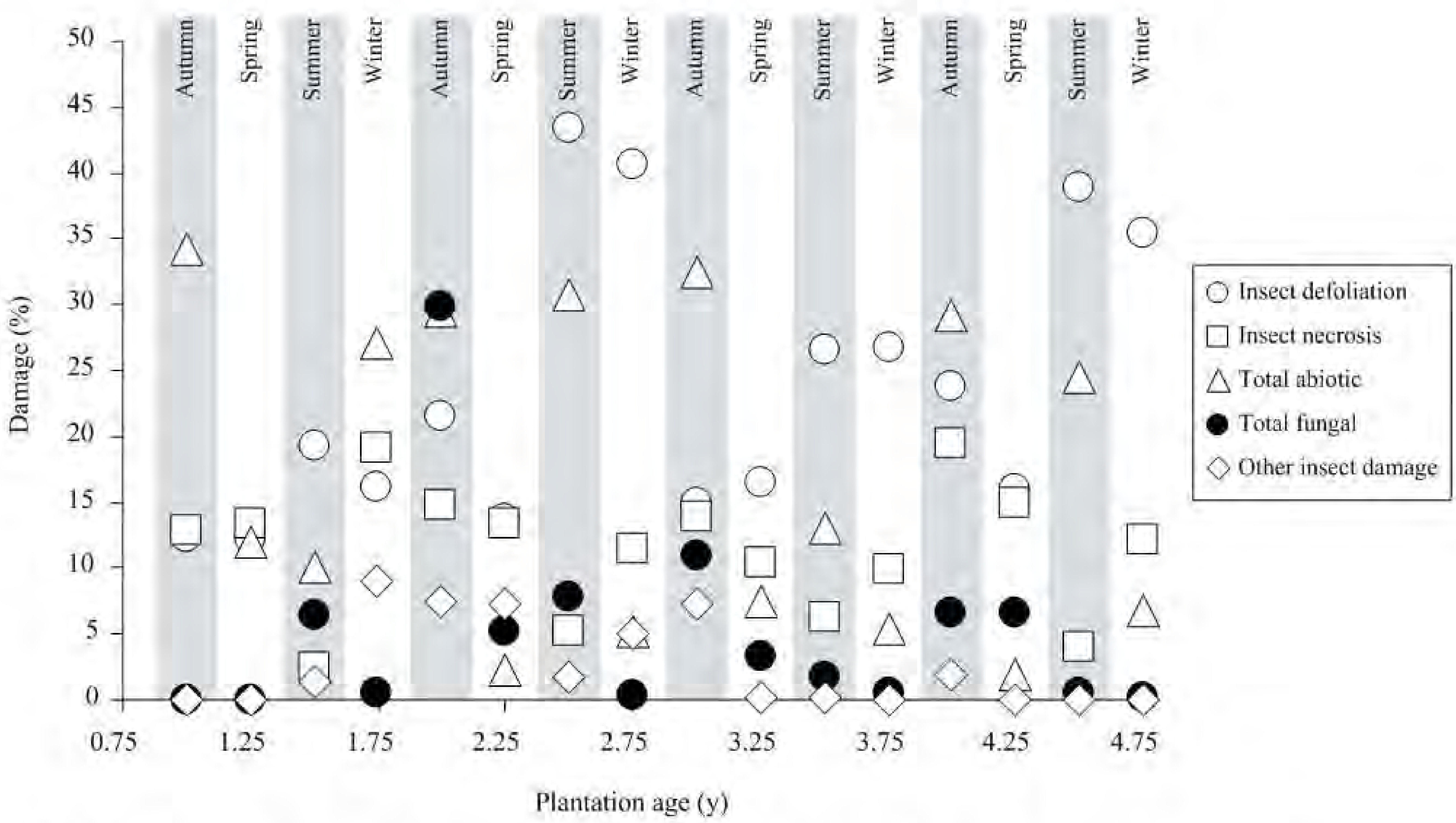

Figure 5. Total damage to foliage over time by pests and pathogens of south-eastern Queensland *Eucalyptus dunnii* plantations

recording leaf damage the levels appear higher in older plantations because they retain leaves. Overall, the damage levels recorded underestimated the true extent of damage because much foliage was lost between assessments. Leaf phenology studies at regular intervals (1–2 weeks) would provide more robust data.

The dry conditions during the survey also potentially decreased the incidence of fungal damage. Even the high summer rainfall event in Bundaberg did not appear to predispose the trees to increased fungal attack. In preliminary surveys very diverse foliar fungi were observed, but as the study progressed the incidence of fungal damage decreased. Fungi belonging to the Mycosphaerellaeceae caused the highest recorded incidence of fungal disease, but did not result in major damage and are not considered to be a problem in plantations in Queensland (Barber *et al.* 2008). Teratosphaeraceae have caused complete defoliation of other *Eucalyptus* species and hybrids in central Queensland (Andjic *et al.* 2010).

Although *E. dunnii* has the capacity to re-foliate quickly, pests have the potential to cause significant damage, and or can pre-dispose the trees to other stress factors (Stone 2005) or further infestations of pests and diseases. Less damage was observed in the 1-y-old plantations than in older plantations, particularly in the first 6–9 months of the survey. It takes time for pest and disease populations to establish and multiply in these small saplings, which during dry periods may lose foliage more quickly than older plantations. We consider the monitoring of young plantations to at least 2 y of age is crucial to their management. Predicting the seasonal appearance and duration of pests and diseases is essential for effective application of control measures.

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